TWO-LAYER PATTERNED RESISTOR

Field of the Invention

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This invention is related to resistors that are patterned on a substrate.

Background

10   Screen printed resistors are used extensively in many types of electronic products. For example, a circuit board in a cellular handset can have more than 200 resistors. In many instances, these are embedded within a layer of the circuit board, so as to leave room for larger parts on the exposed surfaces. Embedded resistors are presently fabricated with width and length as

15   small as 250 microns, using laser trimming to obtain a desired value within an acceptable tolerance (e.g., 1 %). It is desirable to reduce the dimensions of the resistors, consistent with overall product size reduction. Even the current dimensions, however, are challenging. Reducing width substantially below 250 microns is difficult, because typical minimum laser kerfs are about 50 microns,

20   making it difficult to fine tune the resistor value within acceptable tolerances. Reducing length substantially below 250 microns is difficult, even when the width is greater than 250 microns, because a second laser kerf, either parallel to or perpendicular to the first cut, is typically used to fine tune the resistor value after a first kerf has been used for coarse tuning, and very short resistors

25   will not accommodate a second cut.

Brief Description of the Drawings

The present invention is illustrated by way of example and not limitation

30   in the accompanying figures, in which like references indicate similar elements, and in which:

FIGS. 1, 2, 4, 6, 7, 8, and 10 are plan view drawings of patterned resistors that are being fabricated on portions of a substrate, in accordance with embodiments of the present invention;

FIGS. 3 and **11** are cross section view drawings of patterned resistors that are being fabricated on portions of a substrate, in accordance with embodiments of the present invention;

FIGS. 5 and **9** are simplified graphs of increments of resistance of

5   patterned resistors that are being fabricated on portions of a substrate, in accordance with embodiments of the present invention;

FIG. 12 is a flow chart that shows a method to fabricate a patterned resistor on a substrate, in accordance with embodiments of the present invention, including some of those described herein; and

10   **FIG. 13** is an electrical block diagram that shows an electronic device that incorporates patterned resistors in accordance with the embodiments of the present invention.

Skilled artisans will appreciate that elements in the figures are

15   illustrated for simplicity and clarity and have not necessarily been drawn to scale. For example, the dimensions of some of the elements in the figures may be exaggerated relative to other elements to help to improve understanding of embodiments of the present invention.

20   **Detailed Description of the Drawings**

Before describing in detail the particular patterned resistor in accordance with the present invention, it should be observed that the present invention resides primarily in combinations of method steps and apparatus

25   components related to patterned resistors. Accordingly, the apparatus components and method steps have been represented where appropriate by conventional symbols in the drawings, showing only those specific details that are pertinent to understanding the present invention so as not to obscure the disclosure with details that will be readily apparent to those of ordinary skill in

30   the art having the benefit of the description herein.

Referring to **FIG.1**, a plan view drawing of a patterned resistor **101** that is being fabricated on a substrate is shown, in accordance with an embodiment of the present invention. The substrate, of which a portion **105** is shown in **FIG. 1**, may be any material on which patterned resistors can be formed, and may

typically be an inner layer of a multi-layer printed circuit structure, although such need not be the case. For example, the substrate may be a layer of glass epoxy material, of which one well known example is the type designated FR4, or a layer of ceramic material such as alumina, or a layer of polyimide. The

5 patterned resistor **101** at the stage of fabrication shown in **FIG. 1** comprises two conductive end terminations **110** that are on the substrate and a pattern of first resistive material **120** that has a first width **125** and a first sheet resistance. Each of the two conductive end terminations **110** has a conductive connection **115** to some other electrical component or connector. A layer of the first

10 resistive material is applied on the surface of the substrate between the two conductive end terminations **110** in order to form the pattern of first resistive material **120** of the resistor **101**, and also to form (typically) many other patterns of first resistive material for other resistors. In this first embodiment of the present invention, the pattern of first resistive material **120** also extends

15 onto the two conductive end terminations **110**. The layer of first resistive material may be applied by any method for applying a substantially uniform layer of resistive material that can be patterned. Examples of such application techniques are screen printing, stenciling, direct writing, and foil lamination. In some of the application techniques, the application and patterning may be two

20 steps. The foil lamination technique is an example for which a second step could be used to form the patterns. The substantially uniform layer is characterized by a layer thickness, which is an average thickness of the layer of first resistive material. In an example of resistive material that is applied by screen printing carbon-phenolic resistor material, the layer thickness may be

25 approximately 12 microns. The layer of first resistive material has a resistance characterized by a sheet resistance for the layer thickness being used, measured in units of ohms per square, as is well known in the art. In this embodiment of the present invention, the width **125** of the pattern of first resistive material **120** is approximately 125 microns, and the ohms per square

30 is relatively low, such as 40 ohms per square. The width of 125 microns is substantially smaller than the smallest widths commonly used for fabricating conventional patterned resistors. In the example illustrated in **FIG. 1**, the resistor **101** is about 6.25 squares, so the nominal resistance is about 250 ohms. Process variations cause the pattern of first resistive material **120** to

have an offset **130** between the average centerline of the long axis of the pattern of first resistive material **120** and the respective centerline of the two conductive end terminations **110** which does not cause a variance from a desired resistance value for the pattern of first resistive material **120** of the

5   partially fabricated resistor **101**. (The centerline of the two conductive end terminations **110** may alternatively be described as the design, or ideal location of the first resistive material **120**, irrespective of where the conductive connections join the conductive end terminations.) However, it will be appreciated that the resistance values of patterned resistors such as partially

10   fabricated resistor **101** typically vary from a desired value due to process and material variations. It is common to fabricate a patterned resistor with dimensions (width and length, or squares, which is the dimensionless value obtained by dividing length by width) such that under all normal process variations the resistance value will be less than the desired value, and then use

15   a laser trim process to trim the resistor value up to the desired value. However, at the width of the pattern of the first resistive material **120** of the present invention, it is very difficult to control the laser cutting process sufficiently to achieve moderately high precision resistances, such as those within 1% of a desired value, because the diameter of a very narrow laser beam of the type

20   needed to cut the resistor material is on the order of 50 microns. If, in the example being described (the width of the patterned layer of first resistance material being 125 microns), the desired resistance is 250 ± 1%, and the actual resistance is 230 (8% low), the trimming of the resistor **101** has to raise the resistance to a value between 247.5 ohms and 252.5 ohms. Furthermore, the

25   expected amount of variation increases for narrower resistors, because the process variations (as percentages) tend to be larger for narrower patterned resistors. Achieving the required trimming precision with economical laser equipment is very difficult.

Referring to **FIG. 2**, a plan view drawing of the patterned resistor **101**

30   that is being fabricated on the portion **105** of the substrate is shown, in accordance with an embodiment of the present invention. In another step of the process to fabricate the resistor **101**, after the layer of first resistive material is patterned on the substrate for all resistors that are designed to achieve their nominal value by using the first resistive material, a layer of second resistive

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material is patterned over the pattern of first resistive material **120**. The resulting pattern of second resistive material **205** has a second width **210** and a second sheet resistance. The pattern of second resistive material **205** at least partially overlies the pattern of first resistive material **120** and extends between

5 the two conductive end terminations **110**, and may also extend onto the two conductive end terminations **110**. The width of the pattern of second resistive material is substantially wider than, i.e., at least approximately 50% wider than, the width of the first resistive material, or at least 50 microns wider than the width of the first resistive material. As for the layer of first resistive material, the

10 layer of second resistive material may be applied by any method for applying a substantially uniform layer of resistive material that can be patterned, and is characterized by a layer thickness. The material may be carbon-phenolic and the layer thickness may be approximately 12 microns. The ohms per square of the layer of second resistive material is relatively high - at least 10 times higher

15 than the ohms per square of the first resistive material. In this example, it is 3,000 ohms per square. The width **210** of the pattern of second resistive material **205** may be approximately the same as the width of the two conductive end terminations **110**. In the example illustrated in **FIG. 2**, the pattern of second resistive material is about 2 squares, so the nominal

20 resistance is about 6,000 ohms. Process variations cause the pattern of second resistive material **205** to have an offset **215** between the average centerline of the long axis of the pattern of second resistive material **120** and the respective centerline of the two conductive end terminations **110**. Such process variations may cause a portion **206** at the ends of pattern of the

25 second resistive material **205** to not be on the two conductive end terminations **110**, which does not substantially affect the benefits provided by the present invention.

Referring to **FIG. 3**, a cross section view drawing of the patterned resistor **101** that is being fabricated on the portion **105** of the substrate is

30 shown, in accordance with an embodiment of the present invention. The cross section view shows the patterns of the first and second resistive materials **120**, **205**, one of the two conductive end terminations **110**, and the portion **105** of the substrate to clarify the relationships of the items.

Referring to **FIG. 4**, a plan view drawing of the patterned resistor **101** that is being fabricated on the portion **105** of the substrate is shown, in accordance with an embodiment of the present invention. After the patterns of first and second resistive materials are formed for at least the resistor **101**, and

5   typically also after the patterns for all resistors being formed by the first and second resistive materials on this layer of the substrate are completed, a coarse tuning step is performed. A laser beam is positioned at an initial position **405** sufficiently far from the centerline **425** of the two conductive end terminations **110** to assure that it will not be within the pattern of first resistive

10   material **120**, and it may also be positioned to assure that it will not be within the pattern of second resistive material **205**. A measurement is taken of the total initial resistance of the resistor **101**. The beam is then moved toward the centerline **425** at a relatively constant rate. As the beam moves, measurements are taken at relatively constant intervals of the total resistance of the resistor

15   **101**. A difference between each of the measurements made while the beam is moving and the previous measurement is calculated to determine increments of the resistance of the resistor **101** while the beam is moved. When the laser beam reaches the second resistive material, the material is cut, forming a kerf **415**.

20   Referring to **FIG. 5**, a simplified graph of the change in resistance per incremental laser cut of resistor **101** is shown, in accordance with an embodiment of the present invention. While the beam is between the initial position **405** and the edge of the pattern of the second resistive material **205**, near position **410**, there are no increments to the total resistance of resistor

25   **101** (these increments have a value of zero). When the beam is at position **410**, it has begun to cut a kerf in the pattern of second resistive material **205** and any increments measured near position **410** may be increased. However, once the beam is fully within the pattern of second resistive material **205**, the measurements of the incremental resistance change due to the incremental

30   increase of the kerf have a relatively constant value **510** that is small and does not change substantially until the beam comes to a position **420** at the edge of the pattern of the first resistive material **120**. Although the kerf **415** causes a significant change in the amount of resistance presented to current flowing between the two conductive end terminations **110** through the pattern of

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second resistive material **205**, the total resistance between the two conductive end terminations **110** is altered by only a small amount for each incremental increase of the length of kerf **415** because the pattern of second resistive material **205** is effectively connected in parallel with the pattern of first resistive material **120**. In the example shown, if the actual resistance of the pattern of first resistive material **120** is 210 ohms (16% below a desired value of 250 ohms) and the actual resistance of the pattern of second resistive material **205** is 6300 ohms before it is trimmed (which is 5% above a nominal value of 6,000 ohms), then initial actual resistance is about 203.2 ohms. The kerf **415** may have changed the value of the pattern of second resistive material to 6350 ohms, so the total resistance at that point is approximately 203.3 ohms. It will be appreciated that the value **510** of the increments is very small, on the order of 0.01 ohms if 10 measurements are made during the cutting of the pattern of second resistive material **205**. It will further be appreciated that the representation in Figure 5 is idealized for simplicity. The change in resistance is not actually linear with respect to laser position. Rather, the flow of current through a cut resistor is a complex function of the length and width of the resistor and the length and width of the kerf. Figure 5 and this discussion assume a linear relationship for simplicity. The actual nonlinear behavior does not substantially alter the arguments made herein that once the laser position is within the bulk of the second resistive material the incremental change in resistance is relatively uniform and small.

At laser position **420** increments in total resistance drastically increase in value, reaching a value **515** that represents the increment of the resistance due to the cutting of the first resistive material near the edge. (As indicated by a discussion above, the increment will actually increase because of the non-linear relationship between the length of the kerf **415** towards the centerline and the resistance).

Referring to **FIG. 6**, a plan view drawing of the patterned resistor **101** that is being fabricated on the portion **105** of the substrate is shown, in accordance with an embodiment of the present invention. A coarse precision is predetermined for the coarse tuning of resistor **101** that is based on the sheet resistances of the layers of first and second resistive materials, the size (in squares) of the patterns of first and second resistive materials **120**, **205**, and

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the precision of control of the position of the laser beam. When the measured resistance reaches a value that is within the predetermined coarse precision of the desired resistance of resistor **101**, coarse tuning is complete and the beam is turned off at end position **505**. In some instances, more than one kerf must

5 be cut into the pattern of first resistive material **120** to achieve a resistance within the predetermined coarse precision without cutting into the pattern of first resistive material **205** using more than a predetermined maximum length **605**. In the present example, the predetermined coarse precision value is 5%, so the kerf **415** is ended when the resistance becomes more than 237.5 ohms.

10   Referring to **FIG. 7**, a plan view drawing of the patterned resistor **101** that is being fabricated on the portion **105** of the substrate is shown, in accordance with an embodiment of the present invention. After the coarse tuning step is completed, a fine tuning step is performed. In accordance with one embodiment of the present invention, the laser beam is positioned on the

15 same side of the resistor **101** as for the coarse tuning cuts, and cutting starts at position **705**, which is the same distance from the centerline **425** of the two conductive end terminations **110** as was the initial position **405** for the coarse tuning. The laser beam is then turned on and moved towards the centerline **425**, cutting kerf **710**. The laser beam is stopped when kerf **710** has reached a

20 maximum length **715** that has been predetermined such that the kerf **710** will not cut into the pattern of first resistive material **120** under all process variations that cause changes to the offset **130** of the pattern of the first resistive material with reference to the centerline **425**. Because this restricts the amount of first resistive material that is cut by the kerf **710**, a plurality of kerfs **710, 720, 725**

25 are cut in order to bring the final resistance of the resistor **101** to within 1% of the desired value (e.g., 2.5 ohms for the desired 250 ohms). In this example, it is assumed that the length of resistor 101, the thickness of the kerfs, and the precision of control of the laser are such that the kerfs 415, 705, 710, 720 provide adequate change to the total actual resistance of the resistor 101.

30 Typically by today's standards, such cuts should be separated by approximately 175 microns. It will be appreciated that, in this embodiment, there will be instances in which kerfs that are made from one of the two sides of the resistor **101** may not be able to be cut into the pattern of second resistive material **205** at all. This result is due the constraint used to avoid cutting into

the pattern of the first resistive material **120** under all process variations, as illustrated by the initial position **730** and final position **735** of an attempted laser cut on the side opposite the kerfs **710, 720, 725** that is limited to a length **740** equivalent to length **715**.

5   Referring to **FIG. 8**, a plan view drawing of the patterned resistor **801** that is being fabricated on a portion **805** of a substrate is shown, in accordance with another embodiment of the present invention. The resistor **801** is of the same dimensions as resistor **101** described above, but the offsets of the patterns of the first and second resistive materials **815, 820** are oriented

10   differently with reference to the two conductive end terminations **810** and the initial position **825** of the laser beam in the coarse tuning step than the offsets described with reference to resistor **101**. The coarse tuning step is begun at the same position that was described above for resistor **101**. Refer also to **FIG. 9**, which is a simplified graph of the increments of resistance of resistor **801**, in

15   accordance with an embodiment of the present invention. The increments of the measured resistance of resistor **801** are zero until position **830** is reached, at which point there is a substantial change **910** of the increments of resistance to a low, but non-zero value **915**. When position **835** is reached, a substantial change **920** of the increments again occurs, after which the value **925** of

20   increments becomes very large. Similar to the earlier example, the laser beam is stopped when a resistance of resistor **801** is within a predetermined fine precision of a desired resistance of resistor **801**. In this embodiment, the substantial changes **910, 925** in values of the increments are used to determine the edges of the patterns of first and second resistive materials **815,**

25   **820**. From this determination, a determination may be made as to which side of the resistor **801** offers a larger distance from the edge (also called herein the farther edge) of the pattern of second resistive material **820** to the edge of the pattern of first resistive material **815**, and the fine tuning kerfs are cut from the side having the larger distance, as illustrated by kerf **840**. Additionally, coarse

30   kerf cuts made after the first kerf cut may be initiated from the side having the shorter distance from the edge of the pattern of second resistive material **820** to the edge of the pattern of first resistive material **815**, and the initial position of the laser beam may be moved close to the edge of the resistive material that is related to the tuning being done (i.e., close to the edge of the first resistive

material **815** for additional coarse tuning cuts and close to the edge of the second resistive material **820** for all fine tuning cuts).

It will be appreciated that the benefits derived from determining the positions of the edges of the patterns of the first and second resistive materials

5   could be derived by other means and methods of determination, such as using optics after each layer is patterned, or using a combination of optics and resistance values.

It will be further appreciated that although the kerf cuts described with reference to FIGS. 4-8 are described for simplicity to be continuous channels

10   that are cut essentially perpendicular to the centerline of the respective resistors 101, 801, the term "kerf" or "kerf cut" as used in this document contemplates all variations of resistive material removal that remove incremental amounts of resistive material small enough to permit at least some incremental removals of the second resistive material that do not also remove

15   any first resistive material. This would include, for example, L shaped laser cuts or a series of laser holes punched into the resistive materials, or, for example, incremental resistive material removal by an abrasive means or other ablative means.

Referring to **FIG. 10**, a plan view drawing of a patterned resistor **1001**

20   that is being fabricated on a portion **1005** of a substrate is shown, in accordance with another embodiment of the present invention. In this embodiment, a pattern of first resistive material **1015** has a high sheet resistance and extends between, but is essentially not on, the two conductive end terminations **1010**. A pattern of second resistive material **1020** has a low

25   sheet resistance (at most one-tenth that of the high sheet resistance), and extends between and is on the two conductive end terminations **1010**. A cross section of this arrangement is shown in **FIG. 11** for clarity.

Referring now to **FIG. 12**, a flow chart of a method to fabricate a patterned resistor on a substrate is shown, in accordance with embodiments of

30   the present invention, including some of those described herein. At step **1205**, two conductive end terminations are patterned on the substrate. A first layer of resistive material having a first sheet resistance is patterned at step **1210** to have a first width and to extend on the surface of the substrate between the two conductive end terminations. At step **1215**, a second layer of resistive

material having a second sheet resistance is patterned to have a second width, to extend between the two conductive end terminations, and to at least partially overlay the first layer of resistive material. This becomes a pattern of second resistive material. One of the first and second layers of resistive material are

5   patterned to extend onto the two conductive end terminations. One of the first and second sheet resistances is a low sheet resistance and the other of the first and second resistances is a high sheet resistance. A ratio of the high sheet resistance to the low sheet resistance is at least ten to one.

It will be appreciated that in some instances, no coarse tuning kerf need

10   be cut because the initial measured resistance of the resistor is within the predetermined coarse precision. Thus, an additional step **1225** is fine tuning the resistor using a first trim kerf that is extended solely into the high resistive material. In those instances for which a coarse trim cut is needed, there is an additional step **1230** of coarse tuning the resistor using a second trim cut

15   (which occurs before the first trim cut) that is extended into the low resistance material.

In some embodiments, additional steps are added. At step **1235**, positions of edges of the high resistance material and the low resistance material are determined. The positions of the edges are used at step **1240** to

20   determine a large offset side of the patterned resistor that has a larger separation between the edges of the patterns of high resistive and low resistive materials. At step **1245**, the first trim kerf (the fine tuning trim kerf) is started at the large offset side of the patterned resistor.

In some embodiments, yet more steps are added. The determining of

25   the larger offset side of the patterned resistor comprises measuring increments of the resistance of the patterned resistor during the second (coarse) trim kerf cut at step **1250** and determining the larger offset side from locations of substantial changes of the increments at step **1255**.

Referring now to **FIG. 13**, an electrical block diagram shows an

30   electronic device **1300** that incorporates patterned resistors in accordance with the embodiments of the present invention described above. The electronic device can be any electronic device that uses a printed circuit board **1301** having a power source **1305**. The power source **1305** generates a DC supply voltage **1306** that is coupled to integrated circuit 1 (IC1) **1320**, IC2 **1315**, and at

to least one power decoupling capacitor **1360**. In the case of the electronic device **1300**, the power decoupling capacitors **1360** are coupled to a chassis ground **1350**, as is the power source **1305**. IC1 **1320** generates a signal **1371** that is filtered by a precision resistor **1374** and a coupling capacitor **1370**, and

5 returned to IC1 **1320** as filtered signal **1372**. IC1 **1320** generates another signal **1321** that is filtered by precision resistor **1324** and coupling capacitor **1325**. The filtered signal **1327** is coupled to IC2 **1315**. IC2 **1315** has a radio frequency (RF) output amplifier that is grounded to an RF ground **1340**. An output of the RF amplifier is coupled to an antenna **1310** by a coaxial cable **1330** that is also

10 coupled to the RF ground **1340**. Two de-coupling capacitors **1335**, **1336** provide bypass filtering to the RF ground for two undesired RF signals (e.g., spurious frequencies). In this instance, the two de-coupling capacitors **1335**, **1336** are connected to the RF ground **1340**. The precision resistors **1324**, **1374** are two patterned resistors of many that are fabricated on a layer of the printed

15 circuit board **1301**, the surface of which serves as the substrate described above during the fabrication of the resistors **1324**, **1374**, which uses the techniques of the present invention to achieve a 1% tolerance of their desired values. The precision resistors **1324**, **1374** are coupled through other electronic components (in this case, electronic components within IC1 **1320** and IC2

20 **1315**) to a coupling **1307** to the DC power supply **1305**. The electronic device **1300** is representative of any electronic device that can be coupled to one or more power sources, either AC or DC and that uses patterned resistors of the present invention to perform the functions of such electronic device. A few examples of such electronic devices are partially and fully completed printed

25 circuit board subassemblies, completed electronic kits, cellular telephones, personal digital managers, toys, appliances, test equipment, controllers, computers, weapons, displays, televisions, etc. All such devices may benefit from the present invention.

It will be appreciated that the present invention offers at least two

30 advantages over conventional techniques. The present invention allows precision trimming for very narrow resistors; that is, for resistors including a resistive material that is narrower than 250 microns, because the effect of any kerfs cut into such narrow resistors having only a single resistive material is so large. Additionally, the present invention offers a means for precision trimming

of very short resistors, i.e., those less than 250 microns in length, because cutting a second, precision kerf (such as the leg of an L shaped kerf that is conventionally used for wider resistors) into the resistive material of a prior art, short single resistive material resistor is not practical.

5   In the foregoing specification, the invention and its benefits and advantages have been described with reference to specific embodiments. However, one of ordinary skill in the art appreciates that various modifications and changes can be made without departing from the scope of the present invention as set forth in the claims below. Accordingly, the specification and

10   figures are to be regarded in an illustrative rather than a restrictive sense, and all such modifications are intended to be included within the scope of present invention. The benefits, advantages, solutions to problems, and any element(s) that may cause any benefit, advantage, or solution to occur or become more pronounced are not to be construed as critical, required, or

15   essential features or elements of any or all the claims.

As used herein, the terms "comprises," "comprising," or any other variation thereof, are intended to cover a non-exclusive inclusion, such that a process, method, article, or apparatus that comprises a list of elements does not include only those elements but may include other elements not expressly

20   listed or inherent to such process, method, article, or apparatus.

The term "another", as used herein, is defined as at least a second or more. The terms "including" and/or "having", as used herein, are defined as comprising. The term "coupled", as used herein with reference to electro-optical technology, is defined as connected, although not necessarily directly,

25   and not necessarily mechanically.

What is claimed is: